

Final Performance Report

ONR Special Award In Ocean Acoustics FY98 - FY07

Office of Naval Research Grant N00014-98-1-0117

Performance Period: 1 November 1997 – 31 December 2007

Terry E. Ewart, Principal Investigator

This final performance report summarizes the work accomplished during the past 10 years supported by the "ONR Special Award in Ocean Acoustics" awarded to Terry E. Ewart by Code 321 Ocean Acoustics. The award was sponsored by ONR Program Managers Tom Curtin, Jeff Simmen and, later, Ellen Livingston. The work during this period of time can be outlined as follows:

1. Publication of the results of the 1996 Synthetic Aperture Sonar (SAS) Cruise.
2. Completion of the APL Acoustic Tank by Eric Thorsos and Terry Ewart, and Dr. Ewart's student, Garfield Melema, finished his PhD degree.
3. Validity of the Markov approximation studies with Frank Henyey.
4. The "Detect" algorithm.
5. Collaboration with other investigators.
6. Work in final stages of completion but not published.
7. The dilemma of the upper turning point phase and intensity fluctuations revisited.
8. Collection of the movies and pictures from Dr. Ewart's 52 years of research at APL.

1. SAS cruise

In 1996 we set sail from WHOI to conduct the Synthetic Aperture Sonar Experiment.

With PI's Kevin Williams and Frank Henyey, Dr. Ewart participated in the design, the construction, the conduct, and the analysis of that experiment. He was supported by this grant for the later analysis of the data. The first paper, "Effects of Internal Waves and Turbulence on a Horizontal Aperture Sonar" by Henyey, Rouseff, Grochocinski, Reynolds, Williams, and Ewart was published in the *IEEE Journal of*

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14. ABSTRACT The final performance report summarizes the work accomplished during the ten years of support: 1) Publication of results of the 1996 Synthetic Aperture Sonar (SAS) Cruise, 2) completion of the APL Acoustic Tank associated with Ph.D. obtained by Garfield Mellema, 3) summary of the validity of the Markov approximation studies with Dr. Frank Henyey, 4) description of the "Detect" algorithm, 5) description of collaborations with other researchers, 6) description of work in final stages, 7) revisit of the dilemma of the upper turning point phase and intensity fluctuations, 8) collection of movies/photographs/papers from Dr. Ewart's 52 years of research at APL.						
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Oceanic Engineering and described the experiment and the theory we expected to test. It was followed by a paper on the experimental results, "Internal Wave Effects on High-Frequency Acoustic Propagation to Horizontal Arrays--Experiment and Implications to Imaging" by Williams, Henyey, Rouseff, Reynolds, and Ewart, published in 2001 in *IEEE Journal of Oceanic Engineering*. Frequencies of 6, 20, 75, and 129 kHz were sent between two towers separated by 815 meters. The results indicated that the internal wave field has a significant effect on imaging. During the times when solibores were present, very serious disruption of the acoustic fields was observed. The paper discusses these results in detail.

2. The APL acoustic tank

A proposal to build an acoustic tank with two very precise positioning stages was submitted by Principal Investigators Terry Ewart and Eric Thorsos; it was funded by ONR and completed during this period. The tank system was designed, built and installed at APL and remains an excellent laboratory facility for high frequency acoustic experiments. The system is run by "Labview" and is quite easy to program. Dr. Ewart's PhD student Garfield Mellema did his research to measure the scattering of sound from a machined random rough surface and compared it with perturbation theory. An experiment to test the hypothesis that penetration into the sediments is caused by scattering from random rough surfaces was his goal. This experiment was made possible by using the two stages in the tank to manipulate a source and a receiver. The idea behind the experiment was to understand post critical angle scattering to see if the random roughness produces penetration. If one makes a measurement with a viscoelastic solid surface with random roughness, one can rule out alternative hypotheses. Comparison of the measured and modeled reflection and refraction from the smooth surface demonstrated the accuracy of the apparatus. The machined surface was large enough to allow 200 uncorrelated measurements of the scattering by translating the transmitter and receiver using the stages. Mr. Mellema defended his thesis successfully, and a paper "Near-Grazing Angle Acoustic Scattering Across A Rough Interface Into A Viscoelastic Solid -- Laboratory Measurement and Perturbation Theory Model" by Garfield Mellema, Terry Ewart, and Kevin Williams was published in the *IEEE Journal of Oceanic Engineering*. A second paper that summarizes this research is found in a 2001 *Journal of the Acoustical Society of America* publication "Subcritical Penetration Into a Viscoelastic Solid Due To Interface Roughness -- Laboratory Experiment and Perturbation Theory Model" by Garfield Mellema, Terry Ewart, and Kevin Williams.

3. Validity of the Markov Process

The applicability of the Moment Equations and Path Integrals to ocean acoustics relies heavily on the validity of the Markov approximation. The expansion parameter must be less than one for the Markov Approximation to hold. The Kubo Number is a standard parameter that many authors have shown to be sufficient for Markov to hold. We showed that this parameter is too pessimistic for the ocean case. This issue is discussed in great detail in a 2006 *Journal of the Acoustical Society of America* paper by Frank Henyey and Terry Ewart, "Validity of the Markov Approximation in Ocean

Acoustics.” The paper carefully lays out when the condition is appropriate and when it is not. An Acoustical Society of America talk on this material was also given during this period.

4. The “Detect” algorithm

In the 90’s, Frank Henyey and Terry Ewart developed a new form of a generalized matched filter algorithm they termed “Detect.” Work has continued on this algorithm to the present day in the context of several efforts at APL. The most recent of these is its use in the IED project at APL. Dr. Ewart also proposed this algorithm in a project to acoustically detect, simultaneously with the Cerenkov light detection, very high-energy cosmic ray neutrinos at the deep underwater laboratory in Greece.

5. Collaboration with other investigators

Over the years, Dr. Ewart has collaborated with many scientists from the University of Washington and from other institutions. His collaboration with Charles Macaskill of the University of Sydney continues from 1979. Dr. Ewart visited Prof. Macaskill in Sydney in 2001, and they still collaborate through e-mail communications to the extent of reviewing some of each other’s work and ideas. At APL and the University of Washington, Dr. Ewart has collaborated with a wide range of scientists including Dan Rouseff, Bradley Bell, Kevin Williams, Eric Thorsos, Darrell Jackson, Jim Riley (UW Mechanical Engineering), and Jim Ritcey (UW Electrical Engineering Dept.).

His longest collaboration (since 1979) is with Professor Barry Uscinski of DAMTP at Cambridge University. In the period 1998 – 2000, Dr. Ewart acted as consultant and technical advisor to Professor Uscinski and the Cambridge Ocean Acoustics Group in devising the Acoustic Shadowgraph Method. Initial trials of the method were reported in Waves in Random Media (1999), Vol. 9, 1. In the period 2000 - 2003 Dr. Ewart acted as technical advisor to Prof. Uscinski and his research group in the project to construct the new Acoustic Shadowgraph Device and deploy it at Vesteris Bank in the North Greenland Sea to monitor convection processes. This work was reported in Waves in Random Media (2003) Vol. 13, 107. In the period 2003 – 2007, Dr. Ewart was a joint investigator in an ONR NICOP Project (Award N00014-04-1-0472). His support for this work came from this Grant. The research was aimed at investigating ways to detect submerged sound sources by making use of the scattering characteristics of ocean internal waves. This work was reported in Waves in Random and Complex Media (2005), Vol. 15, 339-352. In 2005, Dr. Ewart organized a course in Propagation and Scattering given at APL by Dr. B. J. Uscinski. In the latest work with Prof. Uscinski, Dr. Ewart will be involved as an advisor in the next stage of the Cambridge ONR project for FY09-10.

Most recently Dr. Ewart has collaborated with Prof. Jim Riley of the UW to use some old SPURV horizontal run results to test newer ideas in ocean internal wave theories. Dr. Ewart is always available for collaboration with anyone at the University of

Washington, and he takes great pride in working with his long time colleagues as well as the younger scientists.

6. Work in final stages of completion, but not yet published

There are three research topics in this category where the work is nearly done, but some calculations are needed to complete the work. On all of this work, talks have been presented at ASA meetings. The three topics are: the study of the pdf of Intensity for Ocean WPRM; the Multi-Dimensional Matched filter with complex amplitudes; and the representation of Third Moments in ocean WPRM. The work that Frank Henyey and Dr. Ewart have devised, i.e., a much better way to compare the measured probability distributions of intensity in ocean WPRM with appropriate models, is extremely important. This research is centered around the application of the Generalized Gamma Distribution to represent ocean WPRM, which Dr. Ewart proposed for the pdf of intensity for ocean acoustic WPRM in the '90s. An important addition to that work has been to utilize the Anderson-Darling goodness of fit test rather than the Kolmogorov-Smirnov test. The AD test is far better able to test the high and low tails of these intensity pdfs. The second research area is to work with Bradley Bell to complete the MDMF for complex amplitudes. The third is work with Frank Henyey on the representation of the third moments of amplitude in ocean WPRM. In addition to publishing the work begun under this grant, we want to put the material on the Web.

7. Re-visit the dilemma of the ocean upper turning point intensity fluctuations

While scientists have sent sound hundreds of convergence zones in the ocean in various experiments over the years, we simply cannot predict even the second moment of intensity for the upper turning point. This was exemplified by the complete failure of Moment Theory or Path Integral Theory to explain the results from the upper turning point data taken during the 1977 MATE experiment. Recent work by Frank Henyey on long-range acoustic propagation has provided us with theoretical constructs that may help to unravel this dilemma. This has been the subject of discussions between Dr. Ewart and Frank Henyey for most of the years of this grant. Professor Uscinski has also weighed in on this very important lack in our understanding of ocean WPRM.

8. Collection of the movies, photographs and papers from my 52 years at APL

Dr. Ewart collected and organized movies, photographs and papers from his 52 years at APL in order to prepare for the three "Science at Sea" lectures, which he delivered over a three-week period in April-May of 2008. Much of the work described in the lectures was research supported by this grant. The movies and photographs have been digitized and will be given to APL management. ONR will receive copies of all materials as soon as they are catalogued and ready to deliver. A DVD of the viewgraphs from the 3 lectures is available; APL has DVD's of the video recordings of the lectures, a copy of which will be made available to the Office of Naval Research, Ocean Acoustics Code.